Transmission Asymmetry in Nano-opto-mechanical Metamaterials at μW Optical Power

Jinxian Li¹, Kevin F. MacDonald¹, Nikolay I. Zheludev¹, ²
1. Optoelectronics Research Centre & Centre for Photonic Metamaterials, University of Southampton, UK
2. Centre for Disruptive Photonic Technologies, SPMS & TPI, Nanyang Technological University, Singapore

In linear optics, the transmission of absorbers is identical in the forward and backward propagation directions. We demonstrate a nonlinear metamaterial with intensity-dependent transmission asymmetry at 30 μW.

Asymmetric Transmission via Optomechanical Nonlinearity

Conventional approaches to asymmetric transmission

- Magnetic field (esp. the Faraday effect)
- Nonlinearity (at high light intensity)
- Mode/polarization conversion

- We utilize opto-mechanical nonlinearity:
  - Strong nonlinearity at low intensity via coupling of optical and mechanical resonances in an all-dielectric metamaterial
  - Nanoscale structural reconfiguration driven by optical forces
    → directionally asymmetric change in optical properties

Metamaterial Optical & Mechanical Resonances

- Optical resonance
  - NIR (telecom C-band) optical resonance
  - Q ~ 27

- Mechanical resonance
  - Si/SiN bilayer structured by focused ion beam milling
  - Thermal (Brownian) motion detected at beams’ fundamental resonant frequencies
  - RMS displacements of ~250 pm

Optically-induced Transmission Asymmetry

- Experiment requires identical FWD/BWD path & illumination conditions, i.e. power, spot size, polarization.
- Pulsed 1550 nm, 30 μW pump beams drives motion at beams’ mechanical resonance frequencies
  → Transmission change for CW 1540 nm probe.
- Complex pattern of frequency- and pump power-dependent oscillatory modes
- Backward-Forward difference up to ~23% at μW pump powers

Summary

- Nanoscale displacements of meta-molecules lead to strong changes in metamaterial optical properties
  - Mechanical nonlinearity coupled to optical resonance provides giant optical nonlinearity
  → Nonlinear asymmetric transmission at μW/μm²

Metamaterial of Si nano-bricks on flexible, free-standing SiN beams
- Optical forces induce nanometric relative displacements of beams differently for FWD and BWD illumination directions
  → Strong differential mode conversion
  → Spectral dispersion of transmission different for FWD/BWD directions

www.metamaterials.org.uk